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Park et al. Reply

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Park et al. Reply: In the preceding Comment [1], Piriz et al. criticize several aspects of the interpretation of the laser-driven Rayleigh-Taylor (RT) experiments on vanadium [2]. Their claim is that it is inappropriate to use a phenomenological viscosity model to analyze the ripple growth, and that an elastic-perfectly plastic model should be used instead. They claim that the effective viscosity depends significantly on the initial ripple amplitude. Both the viscosity model we used and the elastic-perfectly plastic model of Piriz et al. are simplified phenomenological models. As we explain below, the viscosity model has more of the desired characteristics of a successful phenomenological model: it represents the microscopic physics operative in the high-rate regime; it is sufficiently simple that it admits powerful analytic solutions for the RT growth; and finally, it matches the experimental data better.

In experiments such as the seminal work of Barnes et al. [3] studying HE-driven RT growth and our experiments which use laser irradiation for a much stronger drive, the solid material is deformed shocklessly at extremely high strain rates, in our case $\dot{\varepsilon} \sim 10^7$/s. At high rates, dislocation flow associated with strength is in the 'phonon drag' regime [4]. Recently it was shown that a multiscale plasticity model based on first-principles quantum calculations and information passing through a hierarchy of length scales is able to predict the RT growth observed in our vanadium experiments *without any adjustable parameters* [5]. Unlike the phenomenological models (our viscosity model [2], the elastic-plastic model of Piriz et al. and their ABAQUS simulations [1]), the multiscale model provides direct, testable insight into the mechanisms of plasticity. It confirms the dislocation flow is in the phonon drag regime and that the material response is viscous in the sense that the shear stress is not fixed at a rate independent yield surface (as in the Piriz model), but increases with increasing strain rate: $\Delta\tau = \mu\Delta\dot{\varepsilon}$, where μ is an effective viscosity related to the phonon drag coefficient [2].

Using this fundamental multiscale model we have done a series of 2D numerical simulations of vanadium RT growth at perturbation wavelengths of λ= 40, 60, 100 µm, and initial amplitudes of A_0 =0.6, 0.3, and 0.15 µm. The effective viscosity model was applied to each to the three initial amplitudes at three different times (60, 65, and 70 ns). The 65 ns case is shown in Fig. 1. Regardless of the initial conditions we obtain similar viscosities, 400-500 Poise. Our conclusion, contrary to the claim by Piriz et al., is that while the initial amplitude variation does affect the growth of the instability, it does so to the level of ~ 30%, which is small compared to the variations in the effective viscosity. Inferences beyond the ~30% level would require more refined and detailed analysis. It is also clear from the Figure of Piriz [1] that the results of the analytic viscosity model agree better with the experimental data than their elastic-perfectly plastic model, even in a full ABAQUS simulation.

We note in closing that we are not the first to use an effective viscosity to describe high rate plastic deformation (e.g. Refs. [6, 7]). What is new in our work [2] is the ultra

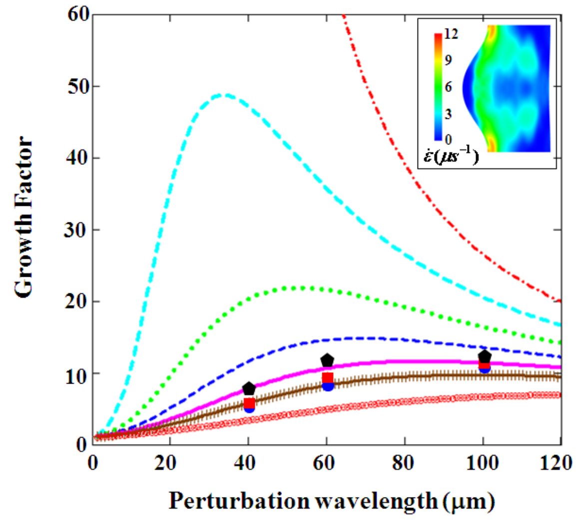

FIG. 1: Simulated dispersion curve for the vanadium-RT experiment at t = 65 ns. Growth factor is plotted versus perturbation wavelength for initial amplitudes of 0.6 µm (black-pentagons), 0.3 µm (red-squares), and 0.15 µm (blue-circles). The smooth curves correspond to the viscosity analysis, assuming viscosities of (from the top) 0, 100, 200, 300, 400, 500, and 800 Poise. The inset shows the high strain rates experienced during the deformation of a ripple.

high pressure, high strain rate regime that drives the plastic deformation into the phonon drag regime, as demonstrated by both the PTW model [2] and the fundamental multiscale model [5]. Further, the demonstration that the plastic flow in the phonon drag regime stabilizes the RT flow (i.e. makes the growth rate lower) and that the time dependent RT growth can be used to infer the phonon drag coefficient in our work, is also new.

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